Innovative management and multifunctional utilization of traditional coppice forests - an answer to future ecological, economic and social challenges in the European forestry sector (EuroCoppice)

Sustainability assessment of chestnut and invaded coppice forests in Piedmont region (Italy)

Østfoldforskning

Participant: Clara Volante

POLITECNICO DI TORINO

Dipartimento Energia

Host institution:

IL DIRETTORE
DEL DIPARTIMENTO ENERGIA
(Prof. MARCO CARLO MASOERO)

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COST FP1301 EuroCoppice:
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Author: Clara Valente

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Summary

The Short Term Scientific Mission (STSM) inside the COST ACTION "Innovative management and multifunctional utilization of traditional coppice forests - an answer to future ecological, economic and social challenges in the European forestry sector (EuroCoppice)" was carried out at Politecnico of Torino (Italy), Department of Energy between 29th September and 10th October 2014.

The goal of the STSM was to assess the sustainability of local wood fuels supply chains for energy production from chestnut and invaded coppice forests in Piedmont region (Italy) in comparison to the wood pellet currently imported from abroad. Hence, three wood energy products were evaluated: wood chips, pelletchips (innovative biofuels able to replace imported pellets from abroad) and wood pellets.

Data concerning wood chips and pelletchips production regarded real case study for two forest companies, Rossetto Legnami and La Foresta. Instead, a theoretical case was built for imported wood pellets.

Environmental, economic and social aspects, when possible, of the wood fuels supply chains were evaluated using the methodology of Life Cycle Sustainability Assessment (LCSA). For the environmental dimension, the report showed results for four environmental impacts categories: global warming, eutrophication, acidification and photochemical oxidation. Results evidenced higher environmental burdens for the wood pellets supply chain compared to the local supply chain of wood chips and pelletchips. Results from the simplified cost accounting showed the potential of pelletchips to have similar hourly costs than wood chips. Social LCA results pointed out as hotspot of the supply chain the very high risk of occupational injuries and fatal accidents for the Italian forestry sector. Indeed, it is to recommend developing new indicators more appropriate for assessing the social impacts of forestry operations.

The Biomass Resource USes and Availability model (BRUSA) developed by the host institution was used for evaluating the woody biomass supply versus the demand for heating from pelletchips specifically for chestnut coppice forests type. The balance among supply and demand was then plotted in GIS maps. In the case study of Rossetto Legnami, e.g., the supply from chestnut coppice forests exceeded largely the demand, highlighting the great potential of satisfying the energy demand using biomass from coppice forests.

The main outcome of the STSM was the development of a methodological framework for assessing the sustainability of wood fuels production from traditional forest coppice through the combination of three tools: LCSA, BRUSA and GIS. This framework can give some answers to decision makers regarding strategic planning addressed to coppice forest management (from the sustainability aspects to the resource availability) and it is applicable in other countries as Scandinavia, after appropriate modifications.

In conclusion, the COST action was a successful networking experience that could lead to future collaboration.

1 Project background

In August 2014, a project application was submitted through Østfoldforskning to the COST action FP1301 EuroCoppice under the call “Innovative management and multifunctional utilization of traditional coppice forests - an answer to future ecological, economic and social challenges in the European forestry sector (EuroCoppice)”. The project entitled “Sustainability assessment of chestnut and invaded coppice forests in Piedmont region (Italy)” was approved and carried out by PhD Clara Valente at Politecnico of Torino (Italy), Department of Energy (i.e. the host institution) from 29th September to 10th October 2014.

Project collaboration and acknowledgments
The participant to the Short Term Scientific Mission, Clara Valente, gratefully acknowledge the support of COST action; the collaboration with the host institution Politecnico of Torino, Department of Energy: Giulio Abdin Cerino, Andrea Crocetta, Michel Noussan, Federica Pognant, Alberto Poggio; the forestry companies: Rossetto Legnami (Enzo and Mirco Rossetto) and La Foresta (Giorgio Talacchini); the private forestry studio (Igor Cicconetti and Andrea Ighina) and ENEA (Roberta Roberto).

2 Introduction

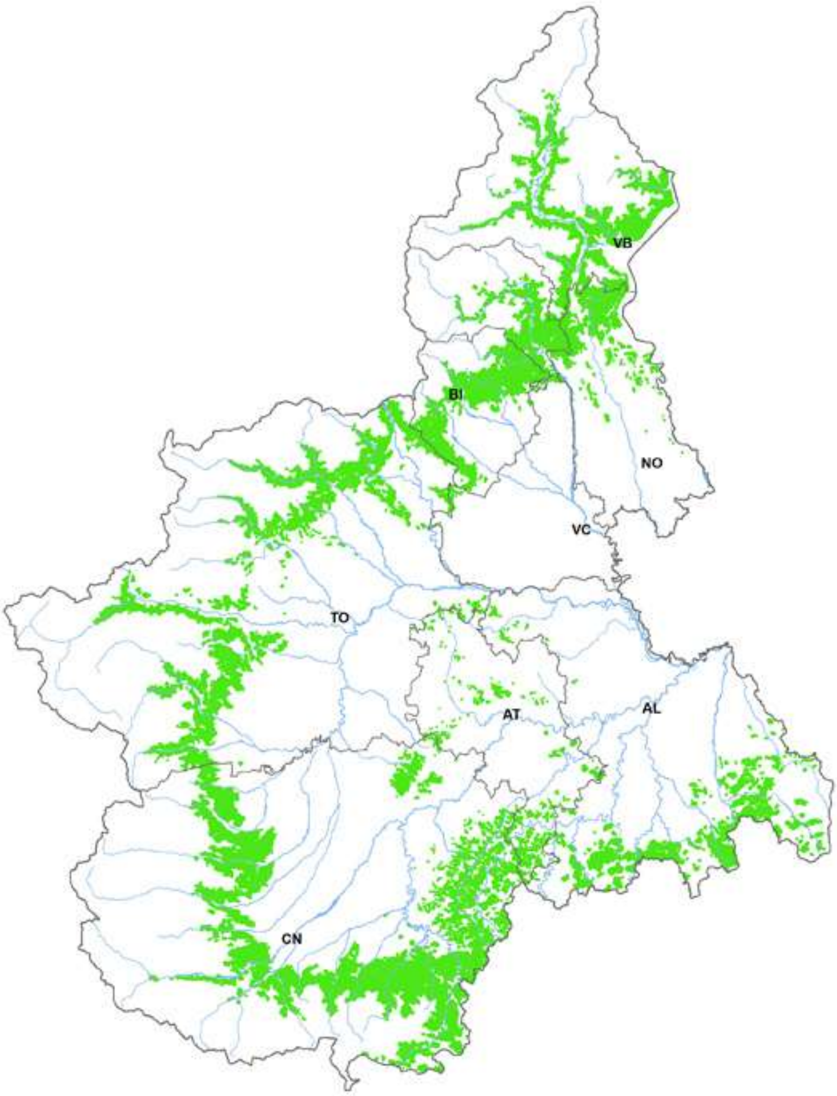
Coppice forests cover almost half of the Italian forested area and it is a relevant sector for both economy and scenic overlook.
According to Ebone et al. (2013) problems related to coppice forests management are due to marginal economic role and difficulties in the forest management practise.
Usually coppicing is more common on private and municipally-owned forests, limiting a common management strategy.
New solutions can stimulate the harvest of coppice forest stands, creating also economic benefits for both forest owners and companies.
In Italy and in particular in those region where coppices are more widespread as Piemonte, woody biomass from coppicing could become a very interesting source of raw material for energy production, in alternative to pellets imported from abroad (today situation).
The focus of the STSM was on chestnut and invaded coppice forests in two specific districts of Piedmont region aimed to energy production.
Traditionally, chestnut coppice is used for firewood production, pole fabrication and extraction of tannin. These conventional uses can change in the next years, when the energy demand for biomass will increase for reaching e.g. the EU Renewable Energy Directive goal of raising the renewable energy share e.g. from bioenergy (EU, 2009).
Hence, it will be necessary to find enough biomass supply for achieving the required energy demand, in the respect of sustainability criteria. It means that the woody biomass should come from local forests, harvested in the respect of forest certification standard, produced and utilized locally and able to generate rural development and jobs.
The goal of the STSM was to develop a methodological framework able to assess the sustainability of wood fuels production from specific coppice forests (in this study chestnuts and invaded forests) and create a tool appropriate for strategic planning of coppice management.
The report is divided in 8 chapter. Chapter 3 describes the methodologies used for assessing the sustainability of specific supply chains, the supply and demand of woody biomass and the geographical location of the study. Chapter 4 presents a detailed description of the case study. Results from each dimension of sustainability, supply versus demand analyses and geographical information system analyses are shown respectively in chapter 5, 6 and 7.
Overall conclusions are pointed out in the final chapter 8.

3 Material and method

3.1. Study area

The STSM study was carried out in Piedmont region (North-western Italy).
In Piedmont, the total forested area is of 874660 ha (http://www.sistemapiemonte.it).
The dominant forest type is chestnut forests (*Castanea sativa* Mill) with a surface of 204670 ha, corresponding to 23.4% of the total forested surface (Figure 1), mainly managed as coppicing.
Beech forests (*Fagus sylvatica* L.) and Locust forests (*Robinia pseudoacacia*) are the following forest types covering 15.5% and 12.4% of the total forested area.

Figure 1 Chestnut forest types in Piedmont region



According to regional law (DCR, 2011), Piedmont region is divided in AiT, "ambiti d'integrazione territoriale", i.e. district having a common land planning strategy.
During the STSM, the focus was on the AiT, Pinerolo and Susa, where respectively the two forestry companies Rossetto Legnami SNC (Luserna San Giovanni municipality) and La Foresta cooperative (Susa municipality) belong to.

More specifically, the case study of Rossetto Legnami was in Pellice Valley, 45 kilometres southwest of Turin, while the forest stands for la Foresta was in Avigliana municipality, about 30 km from Turin.

3.2. Life cycle sustainability assessment methodology

The methodology used for assessing the sustainability of the wood fuels supply chain from coppice forests was the so called Life Cycle Sustainability Assessment (LCSA). It is a recent and developing method for evaluating "all environmental, social and economic negative impacts and benefits in decision-making processes towards more sustainable products throughout their life cycle" (UNEP/SETAC 2011).
LCSA can be expressed as the sum of three methods i.e. Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Life Cycle Analysis (SLCA):

$$LCSA = LCA + LCC + SLCA$$

These three methods were applied to the STSM case study and they should be considered as three ways of looking at the same system. A detailed description of each methodology is presented below.

3.2.1. Life Cycle Assessment (LCA)

The Life Cycle Assessment is a scientific tool for assessing the environmental impact of products, in this specific case wood fuels over the entire life cycle i.e. from "cradle to grave" (Baumann & Tillman, 2004). The analysis considers environmental and resource impacts according to a functional unit for product systems. The potential environmental impacts throughout a product's life cycle (i.e. cradle-to-grave) are evaluated in LCA from raw material acquisition through production, use and disposal.
In this study, environmental impacts were calculated through the use of the LCA calculation software SimaPro version 8 together with the Ecoinvent 3 database (Ecoinvent 2013), a source for life cycle inventory (LCI) data. The use of a database helps to setup complex product systems involving thousands of connected products.
The goal of the LCA was to assess and compare environmental impacts for three wood fuels supply chains:
1) local wood chips production; i.e. *chipped woody biomass in the form of pieces with a defined particle size produced by mechanical treatment with sharp tools such as knives*
2) local pelletchips production; *wood chips of small dimensions having low moisture content and able to be packed in sacks for local energy use* (see Figure 2).
3) wood pellet imported from abroad; i.e. *densified biofuel made from woody biomass with and without additive usually with a cylindrical form*
For technical specification of wood chips and pelletchips, we refer to ISO/EN 17225-1: 2014 (ISO/EN, 2014a) and in addition for wood pellets to ISO/EN 17224-2: 2014 (ISO/EN, 2014b) (see Table 1).

Table 1 Solid biofuels specifications: moisture content, dimensions, net calorific value and bulk density

Wood fuels	Moisture content (%)	Dimensions	Bulk density (BD)	Net calorific value
Wood chips	M25	P45S (particle size): 3.15-45 mm	BD 200: ≥ 200 kg/m^3	3.7 kWh/kg
Pelletchips	M10	P16S (particle size): 3.15-16 mm	BD 250: ≥ 250 kg/m^3	4.6 kWh/kg
Pellet (class A2)	M10	D06 (dimensions): 6 mm (+/- 1 mm) and length: 3.15- 40 mm	BD 600: ≥ 600 kg/m^3	5 kWh/kg

Figure 2 Pelletchips at Rossetto Legnami

The system boundary, i.e. unit processes comprised in the LCA study, includes the extraction of raw material (cradle) to the transportation to the user (gate). Combustion process, disposal phase, end phase are omitted by the analysis. The studied system, including each single steps of the supply chain is described specifically in chapter 4 “case study”.

The functional unit of the system was 1 tons of wood fuels produced and transported to the user.

Tons of wood fuels wass chosen as functional unit, because it is a common unit in the forest sector.
Specific data for the wood chips and pelletchips alternative supply chains come from Rossetto Legnami SNC and La Foresta.
Generic data were supplied by the Ecoinvent database. Factors for calculating environmental impacts are based on the method CML-IA baseline version 3, with the exception for GWP which is based on IPPC 2013 GWP with a 100 year time horizon.
Environmental impact categories selected for the assessment were climate change, acidification, eutrophication, photochemical oxidation with their corresponding indicators global warming potential, acidification potential, eutrophication potential and photochemical oxidation potential. Based on literature sources, they are the most commonly assessed impact categories in forest fuel supply chains (see e.g. Berg and Lindholm 2005). Other environmental impacts such as natural resource depletion and human- and eco- toxicity were not included in the analysis.
Short explanations of these indicators are presented below:
Global warming potential (GWP): shows the relative measure of how much infrared radiation (heat) a greenhouse gas traps in the atmosphere and is measured in kg CO_2-equivalents. The chosen time horizon, since GWPs are calculated for different time spans, was 100 years.
Acidification potential (AP): emissions of gasses (SO_2, NO_x, HCL, NH_3) into the air combine with other molecules in the atmosphere and result in acidification of ecosystems. Acidification is measured in kg SO_2 equivalents.
Eutrophication potential (EP): includes emissions of substrates and gasses to the water and air affecting the growth pattern of ecosystems. EP is expressed in kg PO_4^{-3}equivalents.
Photochemical oxidation potential (POP): often defined as summer smog, is the result of reactions that take place between nitrogen oxides (NO_x) and volatile organic compounds (VOC) exposed to UV radiation. It is expressed in kg C_2H_4-equivalent.

3.1.2. Life cycle costing (LCC)

The life cycle costing is a methodology for assessing all costs associated with the life cycle of a product that are directly covered by one or more actors in that life (Swarr et al. 2011). As for LCA, LCC is directly linked to the life cycle of a product system for assessing the true costs to be compared with another one having the same function.
In economic terms, life cycle is defines as “the sequence product development - production - marketing/sale - end of economic product life”.

However, there are substantial differences between LCA and LCC in time, scope etc.
For performing a complete LCC, costs should come from different stakeholders and collected for each stage of the supply chain. However, due to time restriction and sensitive information, the STSM analysis was limited to a simplified cost accounting, and not a full LCC. The objective was to assess the cost of the wood chips and pelletchips production when possible. The life cycle cost of these two products were expressed in monetary terms, through the quantification of the total hourly cost equal to the sum of fixed and variable costs. The model used for calculating the hourly costs of biomass for each operations followed the excel model presented in the roundwood and wood chips guidelines from the Italian Association of Agroforestry Energy (AIEL 2009).

2.1.3. Social Life cycle Assessment (S-LCA)

Social LCA is a more recent methodology than LCA and LCC. It is also most discussed, but at the same time it is an emerging tool for assessing the social impact of product (UNEP/SETAC 2009).
Social LCA is defined as "a social impact (and potential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle encompassing extraction and processing of raw materials; manufacturing; distribution; use; re-use; maintenance; recycling; and final disposal". In the COST action, the Social Hotspot Database (SHDB) was applied for finding the hotspots and social risks of the Italian forestry sector (www.socialhotspot.org). However, the database helped in performing a screening, but not in making a detailed analysis. Hence, a Health and Safety expert of forestry operations was contacted.

3.2 Biomass Resource Uses and Availability (BRUSA)

In the framework of the Interreg Alcotra RENERFOR project (www.renerfor.eu), the BRUSA model such as Biomass Resources USe and Availability was applied for assessing the local biomass supply from forestry and the residential sector demand.
The goals of the model are to reach a detailed investigation of the biomass resources and uses employed mainly public and open data and to make replicable analyses. The estimation of the local biomass supply and demand in Piedmont Region was carried out by IPLA institute (Institute for Plants and Environment: www.ipla.org).

The BRUSA methodological framework is as following:

I. Estimation of thermal energy requirements for heating at detailed scale (municipality level);
II. Assessment of the number of wood-fired residential heating systems at the reference year 2001 from national census data (ISTAT: Italian National Institute of Statistics; www.istat.it);
III. Reconstruction of wood-fired residential heating devices' sale through a market survey and evaluation of biomass fired system development according to their average life expectancy;
IV. Definition of a methodology for locating new installations inside the studied area;
V. Evaluation of the biomass fuel residential demand, with respect of wood log, pellet and wood chips.
VI. Comparison between actual biomass needs and supply from local sustainable biomass production.

Results from BRUSA pointed out that in Piedmont region (Turin and Cuneo district), the biomass supplied for residential heating purposes was approximately 241 ktoe (wood-log: 174 ktoe; pellet: 63 ktoe; wood chip: 4 ktoe). The amount of energy produced represented 21% of the total residential thermal energy needs (1.171 ktoe in 2011) inside the considered area. The amount of biomass

consumption for residential sector energy supply was equal to 427 ktoe (wood-log: 344 ktoe; pellet: 85 ktoe; wood chips: 7 ktoe).
According to results from the supply side, the sustainable production of wood log was approximately 51 ktoe, covering almost 15% of the total demand, whithin a maximum potential production of 118 ktoe (34% of the total demand). For wood pellets, the local production (9 ktoe) supplied up to 10% of actual demand, while wood chip production (68 ktoe with a maximum potential of 142 ktoe) nowadays covered the total demand of whole sector, equal to 48 ktoe (residential: 7 ktoe; industrial: 38 ktoe; tertiary needs 3 ktoe).

In the STSM, the BRUSA model was adapted for evaluating only the demand of pelletchips, considering as maximum scenario the substitution of all the pellet demand associated to biomass fired plants in the years 2015-2020. In the COST case study, the focus of the analysis was coppice management, with priority to chestnut forest type.
Indeed, a priority list was created and divided in four classes as following:

1. Coppice management of chestnut forests
2. Coppice management of mix forest types (including chestnuts)
3. Coppice and high forests management (mix forest types)
4. Other forest treatment (thinning, regeneration etc.)

3.3 Geographical Information System (GIS)

GIS is a tool for managing and analysing geographical data and creating an informative system aimed to model spatial information.
In the COST action, GIS was a helpful instrument for locating and visualizing in digital maps the resource availability of pelletchips (supply of biomass coming from chestnut coppice forests) and their potential demand (thermal energy needs of the residential sector in winter period) in a range of 30 km from the forestry company Rossetto Legnami and La Foresta. A balance between supply and demand for chestnut coppice was also digitilized in the map.
The input data coming from the BRUSA model were aggregated at municipality level for all the area inside the Provinces of Turin and Cuneo for both supply and demand.

4 Case study

3.1. Rossetto Legnami

During the STSM, data were collected for intensive thinning forestry operations in two forest stands characterized by invaded forests (Pellice Valley), named case study 1 and 2. It is to notice that in Pellice Valley the dominant forest type is chestnuts: 3970 ha managed mainly as coppice.
Both case study were addressed to two different products: wood chips (alternative 1) and pelletchips (alternative 2).
The steps involved along the wood chips are drawn in Figure 3.
In alternative 1 (Figure 3), trees were felled, delimbed and bucked by chainsaw, extracted by tractor with winch, loaded by loader with grapple. A share of the woody biomass was chipped as fresh material (tons fresh matter, case study 1) or after one year left at stack (tons dry matter, case study 2) and transported respectively to a boiler for heating an agglomerate of schools in Torre Pellice, 4 km far away from the forest stand and to the cogeneration plant of Airasca, 30 km away.
Table 2 and Table 3 displays specific data regarding woody biomass amount, productivity, fuel and time consumption respectively for case study 1 and 2. In these tables, the reader should be aware that the amount of woody biomass addressed to chipping is only a share of the total biomass harvested.

Figure 3 Rossetto Legnami, wood chips supply chain, alternative 1. Adapted from forest energy portal (www.forestenergy.org).

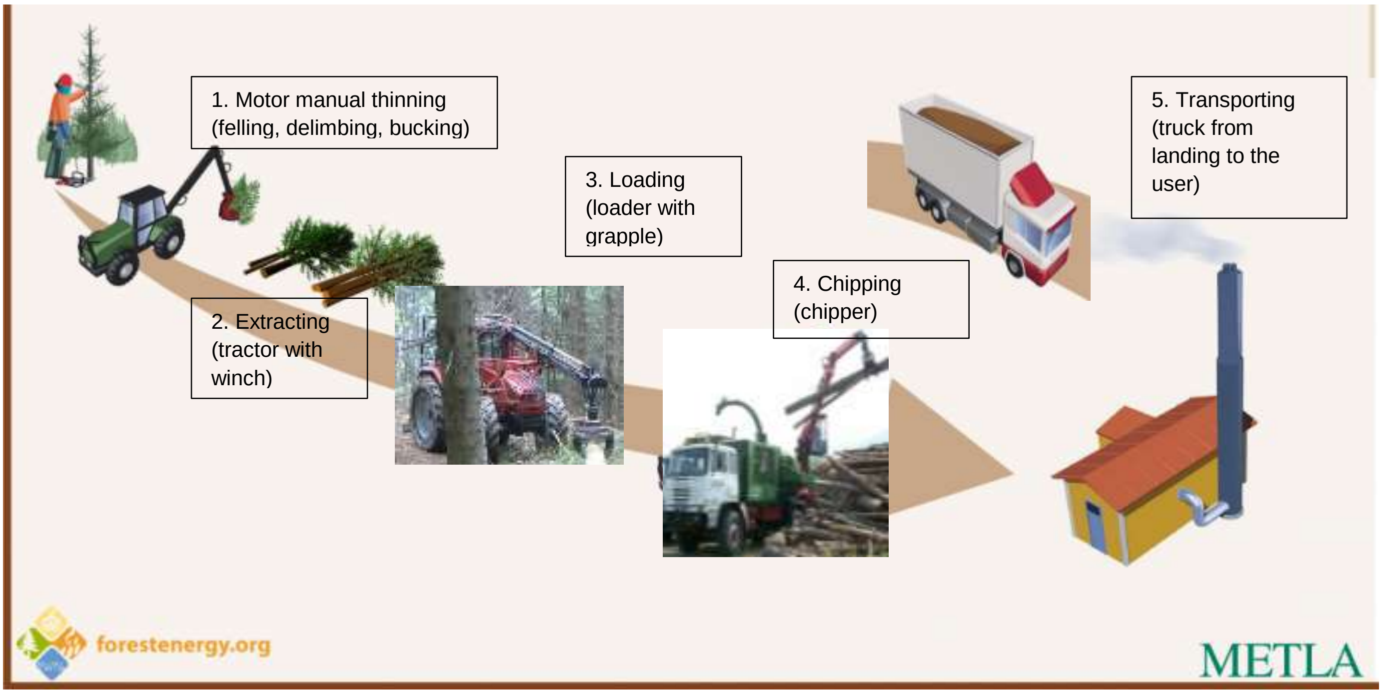


Table 2 Data source: Rossetto Legnami, forestry operations: intensive thinning of invaded coppice forests (case study 1, wood chips, fresh matter)

Forest operations	Machinaries	Fuel consumption (l)	Woody biomass (tons)	Time consumption (h)
Felling, processing, delimbing and bucking at the landing	Chainsaw: Husqvarna 576 XP	12 (petrol for two stroke engine) 6 (lubricant oil)	40	9
Extracting	Crawler with winch: Same Solar 60	26	40	5.5
Loading	Tractor with grapple: Pezzolato Same-Deutz s31s286wvt - Silver	45	40	8
Chipping (Tons fresh)	Chipper: Pezzolato PTH 800/820 M with ventilator	-	25 tons fresh (50% moisture content)	1
Transporting	Truck with trailer (weight: 12.6 tons)	-	15,6 tons (20% moisture content)	-

Table 3. Data source: Rossetto Legnami, forestry operations: intensive thinning of invaded coppice forests (case study 2, wood chips, dry matter)

Forest operations	Machinaries	Fuel consumption (l total)	Woody biomass (tons)	Time consumption (h)
Felling, processing, delimbing and bucking at the landing	Chainsaw: Husqvarna 576 XP	61 l (petrol for two stroke engine) 30 l (lubricant oil)	109 tons	21
Extracting	Crawler with winch: Same Solar 60	125 l	109 tons	15.5
Loading	Tractor with winch: Pezzolato Same-Deutz s31s286wvt - Silver	45 l	109 tons	40
Chipping	Chipper: Pezzolato PTH 800/820 M	-	61 tons dry matter chips (35% moisture content)	1
Transporting	Truck with trailer (weight: 10,8 tons)	-	61 tons dry matter chips	-

In alternative 2, a share of the wood production mix was assigned to the pelletchips production (Figure 4).

The first part of this supply chain was similar to the alternative 1, i.e. from the motor manual thinning to the loading operation, while chipping operations diverged from the conventional chipping due to the use of special knives mounted in the chipper. Furthermore, pelletchips were not transported directly to the customer, but they were screened for removing dust and impurities, dried up for reaching a moisture content of 10%, alike high quality pellets. The drying process allows that these wood fuels can be fed into boilers similar to the pellets ones. This is why the Politecnico of Torino is planning to build up a dryer where solar panels will be utilized. However, during the STSM was not possible to collect data and the measure the consumption and so the emissions for the drying process. Indeed, natural drying was assumed as conventional practise assuming moisture content similar to pellets. The choice of the drier is still under progress, but it is planned to use a solar drier. Actually, it is interesting to know that there are solar driers commercially available promising to dry wood chips from 60 – 40% water content to a water content of 10 – 20% (see e.g. www.cona.at).

The product was bagged in 15 kg bags or big bags of 100 kg. Chip screener and bagging worked in a unique set.

During the field work, the electric power of the screener and bagger and the relative consumption per hour was measured. Indeed, it was not possible to chip fresh and dry matter for pelletchips production, hence it was assumed the same diesel consumption for both materials. Transport distance were assumed of 30 km and 4 km respectively for case study 1 and 2. The same type of truck with trailer for transporting wood chips, was assumed also for pelletchips transportation.

Specific data for chipping, screening, bagging and drying are shown in Table 4.

Table 4 Data for chipping, chip screener, bagging and drying

Operations	Machinaries	Consumption per tons	
Chipping	Chipper: Pezzolato PTH 800/820 M	2.9 l/tons	17 tons/h
Screening	Unique set (special machinaries from Rossetto Legnami)	3.48 kWh/t	-
Bagging		3.65 kWh/t	80 bags/h
Drying	Assumed natural drying	-	-

Figure 4 **Flowchart of pelletchips supply chain**

A costing analysis was performed forestry company Rossetto Legnami. Data were collected for each operation and machinaries, when possible. However, specific data such as repair and maintenance, hourly use of the machines, interest rate etc. were difficult to collect and thus estimated according to personal communication from Politecnico di Torino and foresters. The pelletchips costs for screening and bagging were not available, while it was estimated that the wood chipper had higher purchase price due to the installation of special knives into the drum.

4.2. La Foresta

The case study of La Foresta concerned the wood chip supply chain from one forest stand composed by a mix of deciduous species and dominated by chestnut trees in Avigliana municipality dispatched to cogeneration plant in Airasca (30 km away).

Specific data for each forest operation are shown in Table 5.

Differently from the previous case study, La Foresta is equipped with the harvester and chipper with belt. In the case study of La Foresta, motor manual felling by chainsaw was less intensive operation compared to the Rossetto case study, also because the forest stand was located in flat terrains.

Table 5 Type of machinaries, fuel consumption, wood production, productivity and time consumption

Forest operations	Machinaries	Fuel consumption (l/tons)	Fuel consumption (l total)	Woody biomass (tons)	Time consumption (h)	Productivity (tons/h)
Felling	Chainsaw	0.2	118,5 (petrol for two stroke engine)	834	-	
			50 (lubricant oil)			
Harvesting and processing	Harvester (Kaiser S2 with processor WD50)	2.67	2070	834	172	4.8
Extracting	Excavator with grapple: Neuson with grapple PTK	1.33	1035	834	243	3.5
Chipping	Chipper: Pezzolato PTH 900/660	1.7	543	315	12.5	25.2 tons fresh chips
Transporting	Truck	3.5	1102.5	315	-	-

4.3 Wood pellet import

A theoretical case study was built for modelling a wood pellet supply chain. According to a market analyses of pellets in Piedmont county, led by Politecnico of Torino, DENERG department, most of the pellets has foreigner origin (Table 6). It is expected that the import share from Canada will increase in the next year, justifying the assumption of Canadian origin of wood pellets in this case study.

Table 6 Wood pellet import in Piedmont region

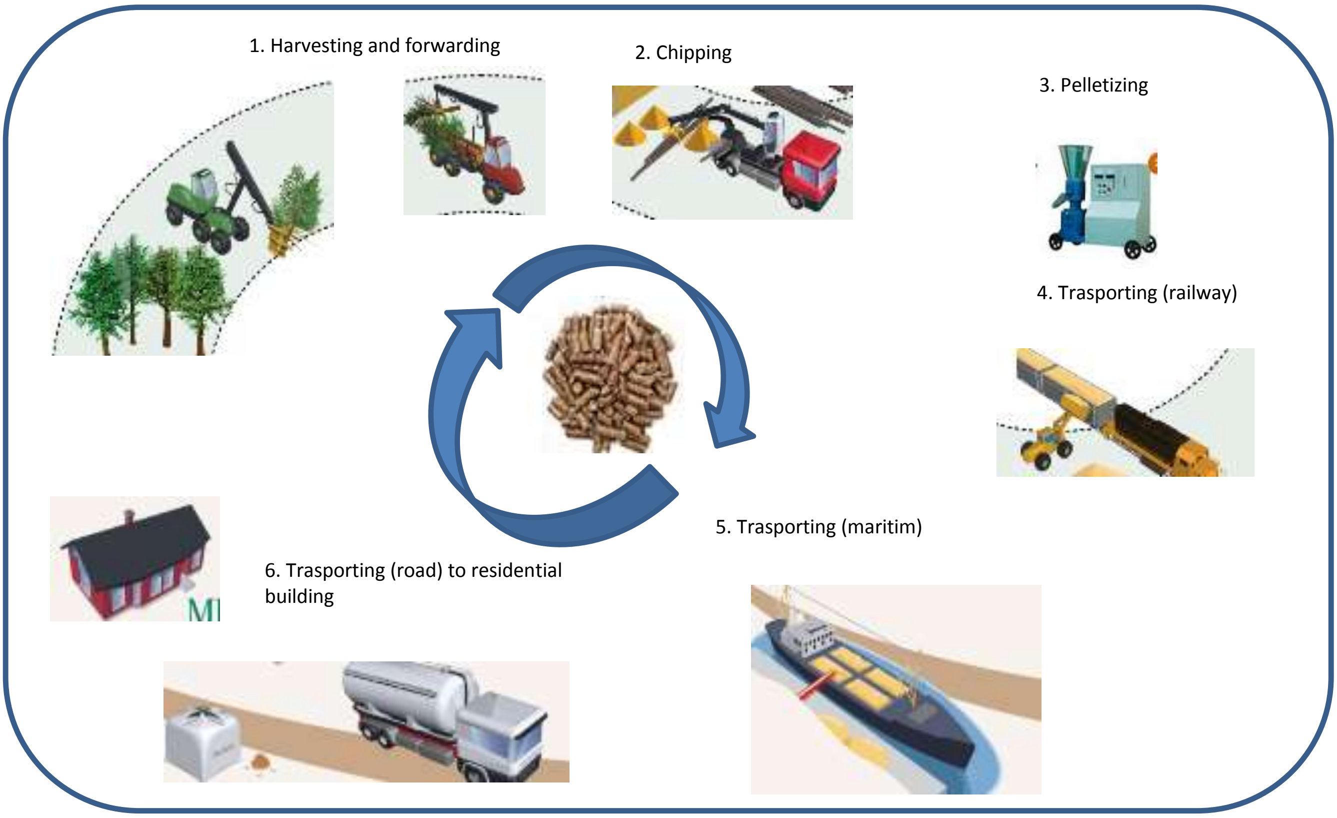
Countries	Import (%)
Other Italian region	5-10%
France	10-15%
Austria	25-35%
Germany	15-25%
Est Europe	10-20%
Canada	10-20%
Other	5-10%

The flowchart of the wood pellet supply chain is described in Figure 5.

The alternative where pellets where transported to harbour closer to the energy user (Genova-Italy) was also considered in the analyses for reducing the road transportation distance. However, it is to notice that

the main trade routes of European pellet volumes are from North America to the Netherlands and Rotterdam is one of the main harbour for imported pellets (Sikkema et al., 2009).
For modelling the pelletizing stage, it was used a generic process card from Ecoinvent database, containing the pressing of pellets out of dried industrial residual wood from planing mill (u=10%). Transports of the input material is included. The volume refers to the bulked volume. Since it is a theoretical case study, this was the most feasible way of modelling this stage. It is necessary to make a quality check of the input data through a detailed data collection in future.
Database data were used for modelling most of the examined stage, while data related to harvesting and forwarding were assumed similar to Norwegian conditions (Flæte, 2009).
Thus, woody biomass was chipped by electric chipper, and pelletized i.e. compacting of wood chips. Conventionally pellets are made from compacted sawdust or other wastes from sawmilling, but for more comparable analyses with the previous case study it was assumed that they come directly from the forest. Wood pellets were transported by railway for 500 km to the Montreal harbour (Canada), shipped for Netherlands (Rotterdam harbour, 5000 km) and then transported by truck to a generic customer located 30 km from La Foresta and Rossetto Legnami. The alternative where pellets where transported to harbour closer to the energy user (Genova-Italy) was also considered in the analyses for reducing the road transportation distance. However, it is to notice that the main trade routes of European pellet volumes are from North America to the Netherlands and Rotterdam is one of the main harbour for imported pellets (Sikkema et al., 2009).
The process card from Ecoinvent database, contains the pressing of pellets out of dried industrial residual wood from planing mill (u=10%). Transports of the input material is already included in the process card. The volume refers to the bulked volume. This is a generic process card for modelling the pelleting stage. Since it is a theoretical case study, this was the most realistic and available process card in the database for modelling this stage. It is necessary to deep the case study with detailed data collection in future.

Figure 5 Flowchart of the wood pellet supply chain



5 LCSA results

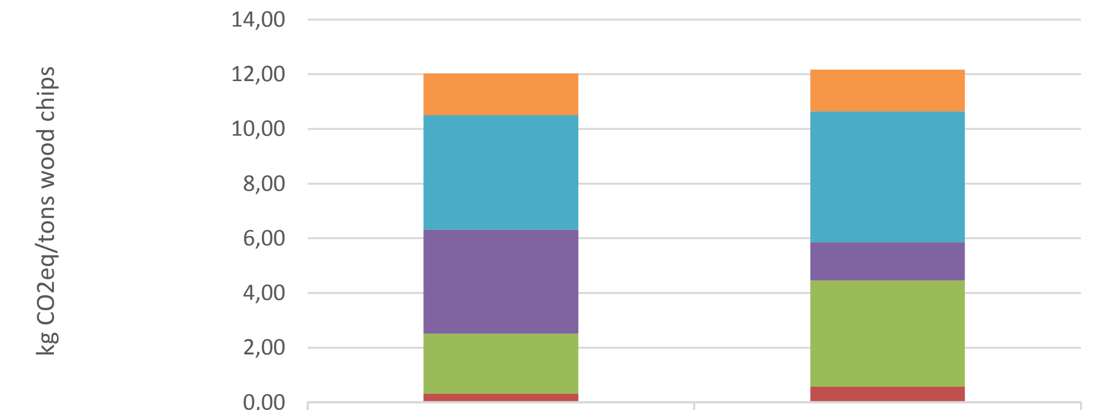
Results from the LCSA are presented for each dimension environmental, economic and social in the sections below.

5.1 LCA results

Results for the different environmental impact categories are presented below for the examined case study.

The Rossetto Legnami wood chips case study (Figure 6) showed a similar emissions for GWP: 12.91 $kgCO_{eq}$/tons and 12.17 $kgCO_{eq}$/tons respectively for case study 1 and 2. In both case study 1 and 2, chipping was the operation having the highest GWP contribution. Extracting operation had higher emissions in case study 2 than case study 1, due to higher fuel consumption in this operation. Chipping fresh matter towards chipping dry matter did not affect the total GWP. Road transportation had a lower contribution (1.53 $kgCO_{eq}$/tons) compared to other forestry operation due to short transport distance to the heating installation in Torre Pellice. Larger GWP contribution for felling operation in case study 2 than case study 1 was due to higher fuel consumption because of lower tree diameters, different delimbing procedure and the presence of underbrush cleaning.

Figure 6 GWP of wood chips supply chain, case study 1 and 2, Rossetto Legnami

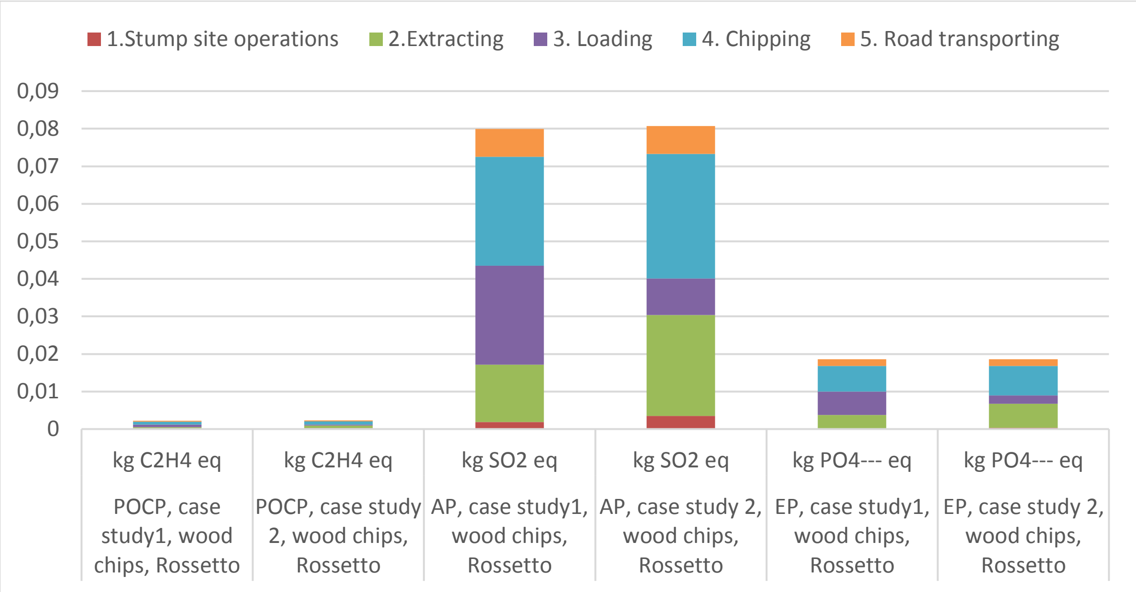


	kg CO2 eq GWP, case study1, wood chips, Rossetto	kg CO2 eq GWP, case study 2, wood chips, Rossetto
5. Road transporting	1,53	1,53
4. Chipping	4,19	4,79
3. Loading	3,80	1,40
2.Extracting	2,20	3,88
1.Stump site operations	0,31	0,58

A similar order of magnitude was found also for photochemical oxidation, acidification and eutrophication potential (Figure 7).

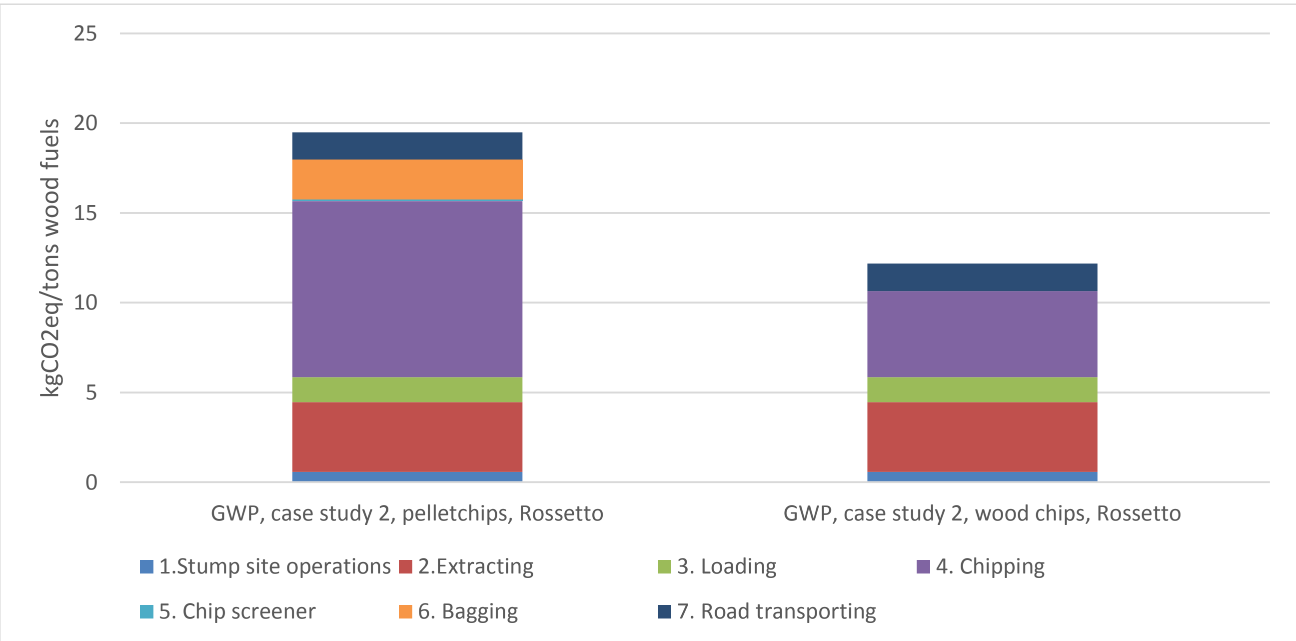
Acidification potential has higher burdens per tons compared to the EP and POCP.

Figure 7 Comparison environmental impact categories (POCP; AP; EP) of wood chips supply chain, case study 1 and 2, Rossetto Legnami



When results from wood chips supply chain were compared to pelletchips supply chains, alternative 2, the total GWP was respectively 19.49 kgCOeq/tons wood fuels, i.e. around 7 higher that for previous result for wood chips. The pelletchips had larger burdens because of two additional stages in the supply chain -screening and bagging contributing respectively for 0.11 $kgCO_{2eq}$/tons and 2.20 $kgCO_{2eq}$/tons- and larger emissions during chipping operations (9.80 for pelletchips compared to 4.78 $kgCO_{2eq}$/tons). The reason might be higher fuels consumption for producing pelletchips due to the use of different knives and lower productivity per hour compared to the conventional wood chips chipping.

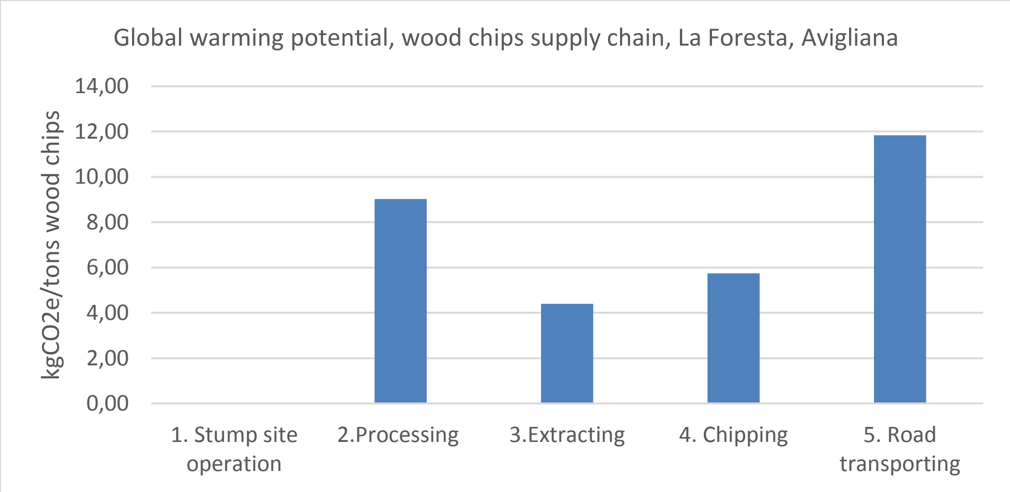
Figure 8 Comparison woodchips and pelletchips supply chains, case study 2, Rossetto Legnami



The wood chips supply chain of La Foresta had higher greenhouse gases emissions than the previous described supply chains (Figure 9). The total GWP was 31 $kgCO_{2eq}$/tons wood fuels compared to 12.17-12.91 $kgCO_{2eq}$/tons of Rossetto Legnami. Road transportation had the highest burdens along the supply chains, due to longer transportation distance to the energy plant (30 km instead of 4 km of Rossetto Legnami). Furthermore, La Foresta had a more mechanized system than Rossetto Legnami. The harvesting operation contributed for 9.03 $kgCO_{2eq}$/tons).

Higher fuel consumption in the different stages of the product chain, more mechanization and longer transportation distance explain larger emissions in La Foresta than in Rossetto Legnami.

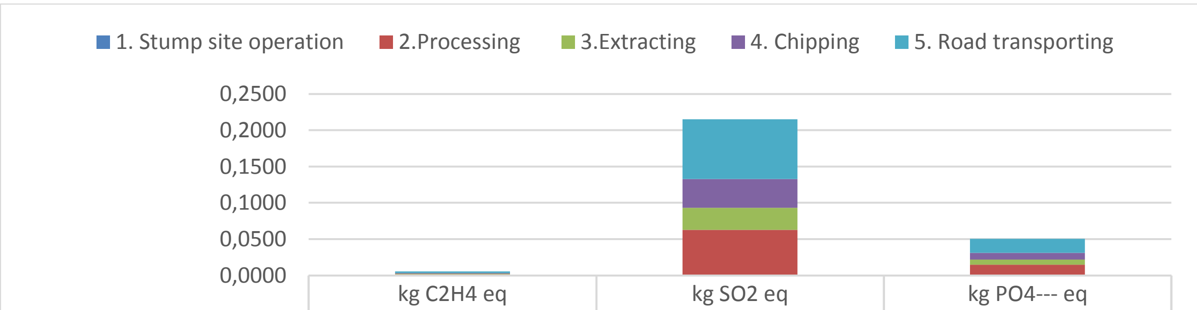
Figure 9 Global warming potential, wood chips supply chain, La Foresta, Avigliana



Regarding the other environmental impact categories the total contribution for AP, POCP and EP (Figure 10) were respectively 0.215 $kgSO_{2eq}$/tons, 0.0055 kg $C_2H_{4\ eq}$/tons and 0.0505 kg $PO_4^{-3}{}_{eq}$/tons.

Processing was the operation with the highest contribution for both AP (0.062 $kgSO_{2eq}$/tons) and EP (0.015 kg $PO_4^{-3}{}_{eq}$ /tons) followed by road transportation (0.082 $kgSO_{2eq}$/tons and 0.019 kg $PO_4^{-3}{}_{eq}$ /tons). Instead for POCP, e it was road transportation having the largest burdens (0.0021 kg $C_2H_{4\ eq}$/tons). GWP for stump site operation has lower contribution than the previous case study, because the supply chain is more mechanized and the motor manual operation by chainsaw are reduced.

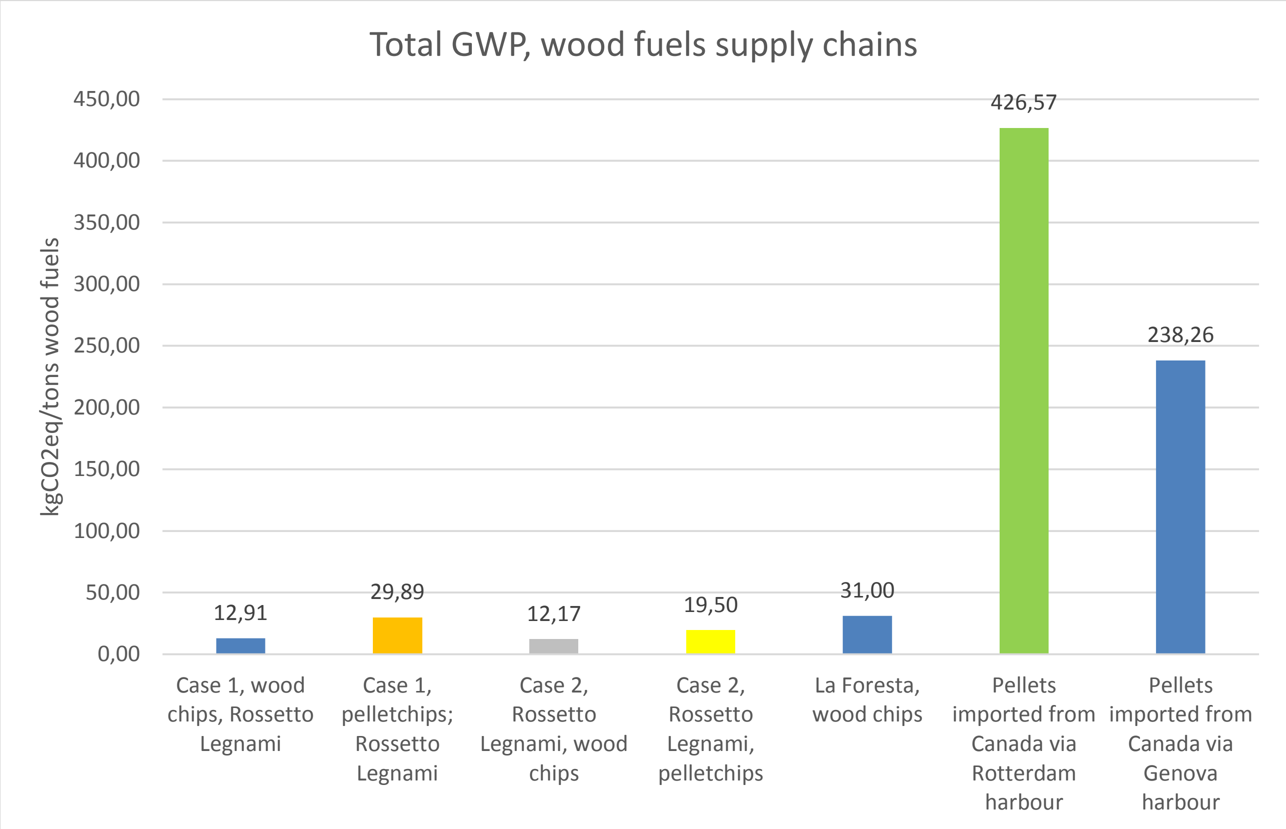
Figure 10 Photochemical oxidation, acidification, eutrophication potential, La Foresta



	kg C2H4 eq Photochemical oxidation (POCP)	kg SO2 eq Acidification	kg PO4--- eq Eutrophication
5. Road transporting	0,0021	0,0820	0,0193
4. Chipping	0,0010	0,0399	0,0094
3.Extracting	0,0008	0,0305	0,0072
2.Processing	0,0016	0,0626	0,0147
1. Stump site operation	0,0000	0,0000	0,0000

In the case study of wood pellet, the total GWP was 426.57 $kgCO_{2eq}$/tons when pellets where imported from Canada via Rotterdam harbour and 238 $kgCO_{2eq}$/tons via Genova harbour (Italy). The stages of the supply chain having largest contribution were transportation to the user. Road transportation by truck from Rotterdam's harbour to Torre Pellice had the highest emissions (229.18 $kgCO_{2eq}$/tons), followed by maritime transportation by freight ship from Montreal harbour to Rotterdam (57.95 57 $kgCO_{2eq}$/tons) and railway transport by electric train (24.18 $kgCO_{2eq}$/tons). Pelletizing had also large burden (95.07 $kgCO_{2eq}$/tons). Forestry operations (harvesting, forwarding and chipping) were the steps having the lowest burdens along the wood pellets supply chain (Figure 11).

Figure 11 Global warming potential, pellet imported from Canada to Piedmont region



High AP emissions are due to incomplete fuel combustion of sulphur oxides (SOx) and nitrogen oxides (NOx) in the forest machinaries. NOx come from fuel combustion in engines and oxidation of atmospheric nitrogen. Stricter norms on sulphur and nitrogen in the fuels or use of catalytic converter for NOX in diesel engines, can reduce the total emissions.

High POCP characterized the transportation phase, justifying why La Foresta and Rossetto Legnami, case study 1, wood chips had alike emissions.

Instead, NOx from fuel combustion is the main contributor to eutrophication emissions.

Table 7 illustrated the comparative analysis for GWP, POCP, AP and EP in all case study.

Pellets imported from Canada, had the highest contribution in all assessed environmental impacts categories.

The wood chip supply chain for la Foresta and the pelletchips value chain for Rossetto legnami had comparable GWP, respectively 29.886 and 30.628 kgCOeq/tons. In the pelletchips case study 1, longer transportation distance (30 km) explained higher burdens for GWP than pelletchips, case study 2. AP

and EP had similar trend to the results for GWP. POCP had alike results for wood chips case study 1 and 2 (0.002 kgC_2H_4 eq/tons), pelletchips case study 1 and La Foresta (0.005 kgC2H4 eq/tons).
High AP emissions are due to incomplete fuel combustion of sulphur oxides (SO_x) and nitrogen oxides (NO_x) in the forest machinaries. NO_x come from fuel combustion in engines and oxidation of atmospheric nitrogen. Stricter norms on sulphur and nitrogen in the fuels or use of catalytic converter for NOX in diesel engines, can reduce the total emissions.
High POCP characterized the transportation phase, justifying why La Foresta and Rossetto Legnami, case study 1, wood chips had alike emissions.
Instead, NO_x from fuel combustion is the main contributor to eutrophication emissions.

Table 7 Comparison of the total GWP, POCP, AP and EP for wood chips, pelletchips and wood pellet import supply chains case study.

Impact category	Unit kg/tons wood fuels	Case 1, wood chips, Rossetto Legnami	Case 1, pelletchips; Rossetto Legnami	Case 2, Rossetto Legnami, wood chips	Case 2, Rossetto Legnami, pelletchips	La Foresta, wood chips	Pellets imported from Canada, via Rotterdam	Pellets imported from Canada, via Genova
Global warming (GWP)	kg CO_2 eq	12.913	29.886	12.173	19.496	31.00	426.572	238.26
Photochemical oxidation (POCP)	kg C_2H_4 eq	0.002	0.005	0.002	0.004	0.006	0.104	0.074
Acidification	kg SO_2 eq	0.086	0.177	0.081	0.125	0.215	3.029	2.116
Eutrophication	kg PO4--- eq	0.020	0.041	0.019	0.029	0.051	0.765	0.543

5.2 Life Cycle Costing results

The results for each stage of the Rossetto Legnami supply chain are shown in Table 8. Results indicated the high costs of chipping operation 172 €/h followed by road transportation by truck 118 €/h.

Table 8 Costing of Rossetto Legnami (€/h)

Costing, Rossetto Legnami	Chainsaw	Tractor with winch	Tractor with grapple	Chipper	Chipper for pelletchips	Truck with trailer
Purchase price euro	901	20600	64000	202942	204942	7500
Economic life years	2	20	20	10	10	25
Use of machine (h/years)	1000	1000	1000	500	500	1000
Recovery value (%)	0%	0%	0%	0%	0%	0%
Repair and maintenance, euro/h	0	10	10	10	10	10
Interest rate, %	4%	4%	4%	4%	4%	4%
Insurance and tax, euro/year	0	316	316	300	300	1765
Fuel cost, euro/h	0,55	4.7	5.6	31.2	31.2	28.6
Personnel cost, Euro/h	24	24	24	27	27	27
Crew, number	1	1	1	1	1	1
Total cost (fixed and variable costs), €/h	**32**	**54**	**59**	**172**	**172**	**118**

5.3 Social LCA results

Figure 12 shows the results in a bar chart as an aggregate social hotspot index (SHI) for five social categories: *community infrastructure, governance, health and safety, human rights, and labor rights and decent work.* The Social Hotspot Indexes compare the country-specific sectors and identify the major contributing themes within a category. An individual index represent each category with a value from 1 to 100, where 1 is the lowest value for the SHI.

Furthermore, each social theme is weighted according to its social risk of contributing to the social category assessed (low risk = 0; medium =1; high= 5 and very high= 10).

Figure 12. Social Hotspot index (SHI) for USA and Norway, shown for the specific sectors forestry and chemical, rubber and plastic products.

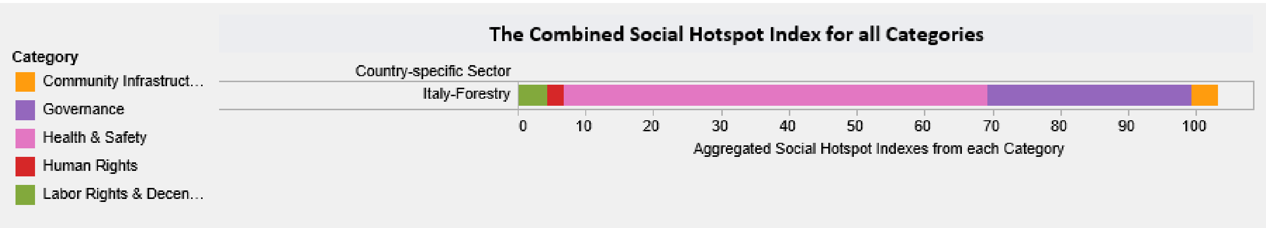


Figure 1 points out that the main social impact is related to the social category health and safety in the forestry sector. The SHI is of 62.5 for H & S category, 30 for governance and less than 4 for the rest of the categories.

According to the SHDB, the risk level for occupational injuries and fatal injuries is very high in the Italian forestry sector, indicating that the attention should focus on improving the health and safety measures.

However, the SHDB highlighted the very high risk of fatal injuries, but it does not explain why. At meanwhile, the risk of death and loss of life year are associated to disease as asthma, mesothelioma, lung cancer etc. (see figure x), while the risk of exposure to noise is low.

Hence, it is necessary to make a more deeply analysis

Figure 13 Risk level for Italian forestry sector (H & S theme)

Risk levels for chosen Countries-specific Sectors (CSS) and multiple issues.

social hotspots database

Theme	Indicator Descriptor	Characterized Issue	Country-specific Sector	Indicator Re..	
Occupational Injuries & Deaths	Fatal Injury Rate by c..	Risk of fatal injuries by country	Italy-Forestry	65	Medium
	Fatal Injury Rate by s..	Risk of fatal injury by sector	Italy-Forestry	11	Very High
	Non-Fatal Injury Rate ..	Risk of non-fatal injuries by country	Italy-Forestry	3.37E+04	Very High
	Non-Fatal Injury Rate ..	Risk of non-fatal injuries by sector	Italy-Forestry	4414	Very High
Occupational Toxics & Hazards	Asbestosis DALYs as ..	Risk of loss of life years by asbestosis due t..	Italy-Forestry	4537	Low
	Asthma DALYs as a r..	Risk of loss of life years by asthma due to al..	Italy-Forestry	5.47E+04	High
	Chronic Obstructive P..	Risk of loss of life years by chronic obstructi..	Italy-Forestry	2.05E+05	High
	Deaths due to occupa..	Risk of death by leukemia due to occupation	Italy-Forestry	1200	High
	Deaths due to occupa..	Risk of death by lung cancer due to occupati..	Italy-Forestry	1.22E+04	High
	Deaths due to occupa..	Risk of death by mesothelioma due to occup..	Italy-Forestry	1100	Medium
	Disability-adjusted life..	Risk of loss of life years by leukemia due to ..	Italy-Forestry	1.00E+04	High
	Disability-adjusted life..	Risk of loss of life years by lung cancer due ..	Italy-Forestry	9.90E+04	High
	Disability-adjusted life..	Risk of loss of life years by mesothelioma d..	Italy-Forestry	1.20E+04	Medium
	Health Care Sector P..	Risk of contracting Hep B or C or HIV from a..	Italy-Forestry	na	###########
	Health Care Sector P..	Risk of contracting Hep B or C or HIV from a..	Italy-Forestry	na	###########
	Health Care Sector P..	Risk of contracting Hep B or C or HIV from a..	Italy-Forestry	na	###########
	Miners' pneumoconio..	Risk of loss of life years by miners' pneumo..	Italy-Forestry	na	###########
	Noise exposure of Fe..	Risk of workplace noise exposure to female..	Italy-Forestry	2.75	Low
	Noise exposure of Fe..	Risk of workplace noise exposure to female..	Italy-Forestry	1	Low
	Noise exposure of Ma..	Risk of workplace noise exposure to males-l..	Italy-Forestry	5.75	Low
	Noise exposure of Ma..	Risk of workplace noise exposure to males-l..	Italy-Forestry	3.5	Low

During the STRM, it was possible to discuss with a safety expert about the development of a methodology for assessing the working risk during forestry operations (Pognant 2014).

The expert has followed the forestry operation of La Foresta in different stands, including the one located in Avigliana.

The Social Hotspot indicators does not seem adequate for evaluating our case study, hence a short list of social indicators for the theme H & S during forestry operations is suggested in Table 9.

Table 9 Social indicators for health and safety in forestry operations

Social indicators (theme health and safety)	Reasons
Risk of Raynaud syndrome, neuro-sensory and osteo-articular disorders	Continuous vibrations
Risk of loss of control	Distraction, misuse of the procedures
Hearing loss	Exposure to noise, misuse of ears protections
Risk of damage to musculature and ligaments	Inappropriate postures
Irritation to the eyes and respiratory tract	Exposure to dust and sawnwood, misuse of visor

Data were collected also for crew number in relation to different stages of the supply chain (Table 10). Results were similar for the forestry company since the small scale of the forest operations. Howevber, it was interesting to know that the whole crew was composed by workers employed locally and having full time contract. This situation is different from Norway, where most of the forestry workers are seasonal workers coming from abroad (especially Poland). Hence, the social indicator rural employment generation is adapt for assessing the sustainability of the local supply chain.

Table 10 Crew numbers for Rossetto Legnami and La Foresta

<table>
<tr><th>Crew number</th><th>Rossetto Legnami (wood chips)</th><th>Rossetto Legnami (pelletchips)</th><th>La Foresta (wood chips)</th></tr>
<tr><td>Felling</td><td>3.5</td><td>3.5</td><td>3.5</td></tr>
<tr><td>Extracting</td><td>1</td><td>1</td><td rowspan="2">1</td></tr>
<tr><td>Loading</td><td>1</td><td>1</td></tr>
<tr><td>Chipping</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Screening and bagging</td><td>0</td><td>1</td><td>0</td></tr>
<tr><td>Transporting</td><td>1</td><td>1</td><td>1</td></tr>
</table>

6 BRUSA results

Results concern the amount of biomass resource available from coppice forests (according to the priority list described in the methodological chapter) in relation to the demand for heat in a range of 30 km from Rossetto Legnami and La Foresta forestry companies and in total for the AiT Pinerolo and Susa respectively to which belong Rossetto Legnami and La Foresta.

Figure 14 illustrates the total estimated supply of wood fuels address to energy (wood chips, firewood and pelletchips) and wood to construction (pole and roundwood) respectively for Rossetto Legnami (left side) and La Foresta (right side). In Rossetto Legnami, the share of pelletchips address to energy was 12 % higher than in La Foresta.

Figure 14 Total supply of wood fuels and wood for construction, Rossetto Legnami and La Foresta

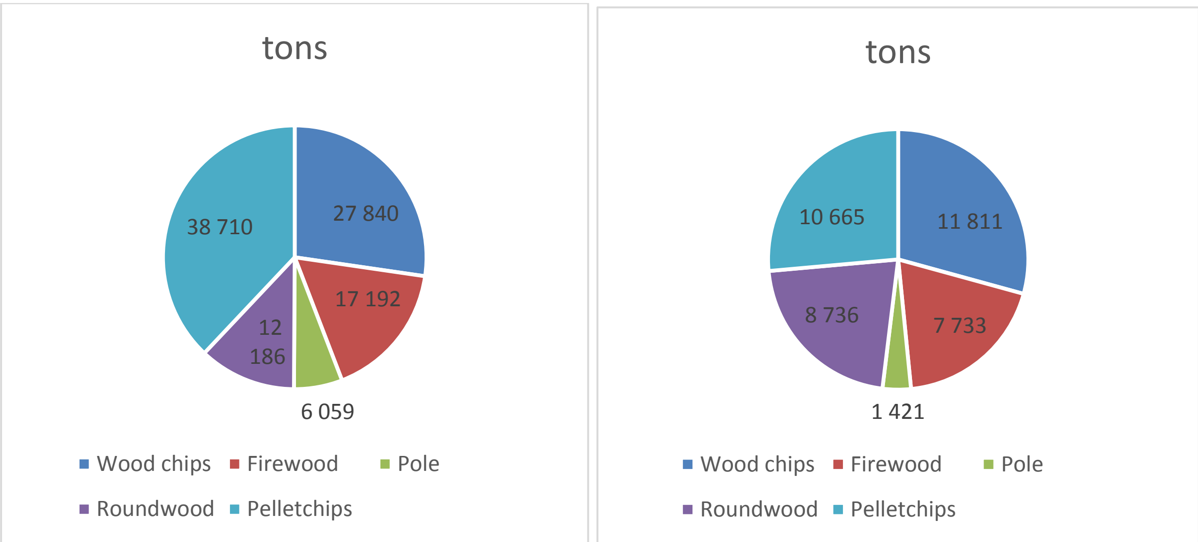
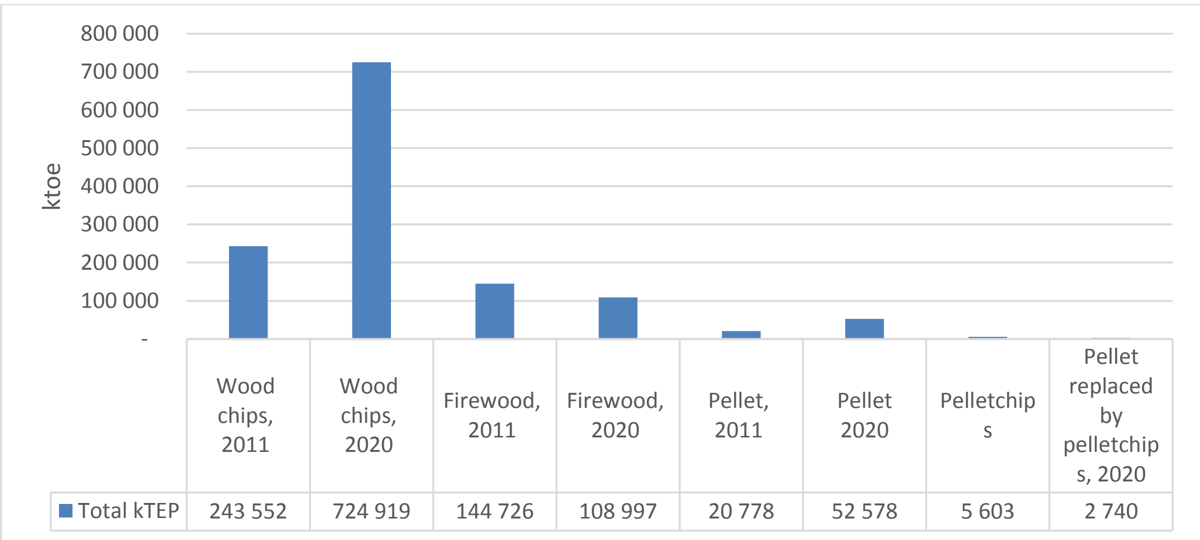


Figure 15 pointed out that wood chips demand will increase drastically to 481362 ktoe from 2011 to 2020. Therefore, the pelletchips will start playing an emerging role in the substitution of pellet, while the demand for firewood will slightly decrease.

Figure 15 Total wood fuels demand in 2011 and 2020 for Rossetto Legnami



Analogous trend for wood fuels demand regards also la Foresta. However, the estimated demand for pelletchips is less than for Rossetto Legnami (Figure 16).

Figure 16 Wood fuels demand, in 2011 and 2020 for La Foresta

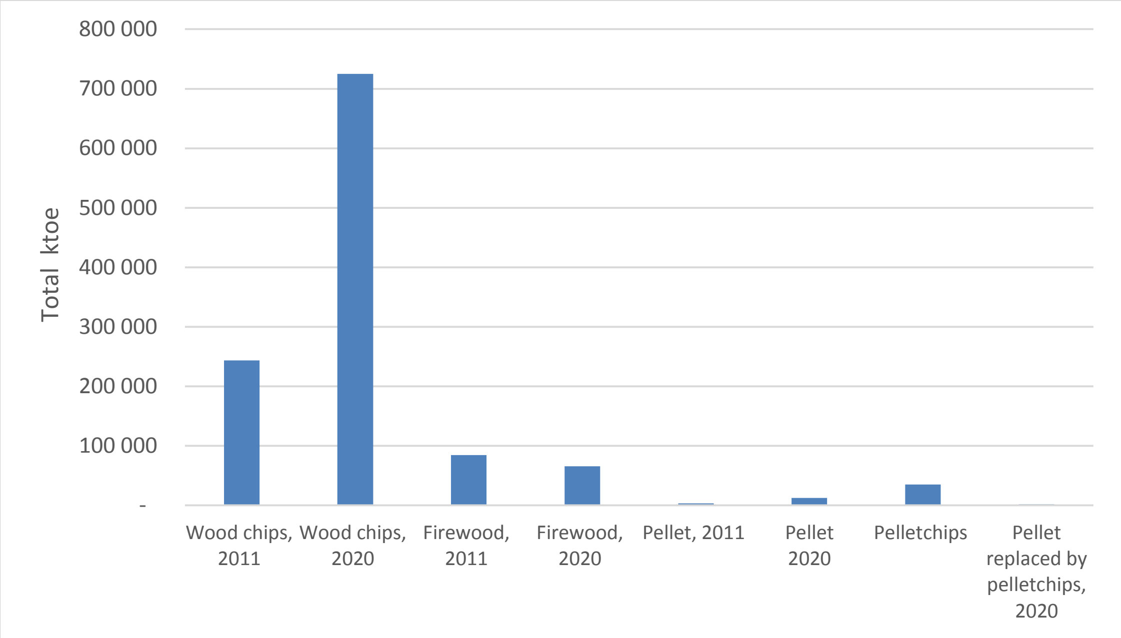


Figure 17 and
Figure 18 shows the balance between resource availability for pelletchips from coppice forests when the chestnut forest type has priority 1 towards its demand respectively for Rossetto Legnami and La Foresta. It was clear that resource available were greater than the demand in Rossetto Legnami, while the opposite result was for La Foresta, where the demand for chestnut coppice will be 17% higher than the resource availability.

Figure 17 Balance between supply and demand calculated on chestnut coppice forests priority list, Rossetto Legnami

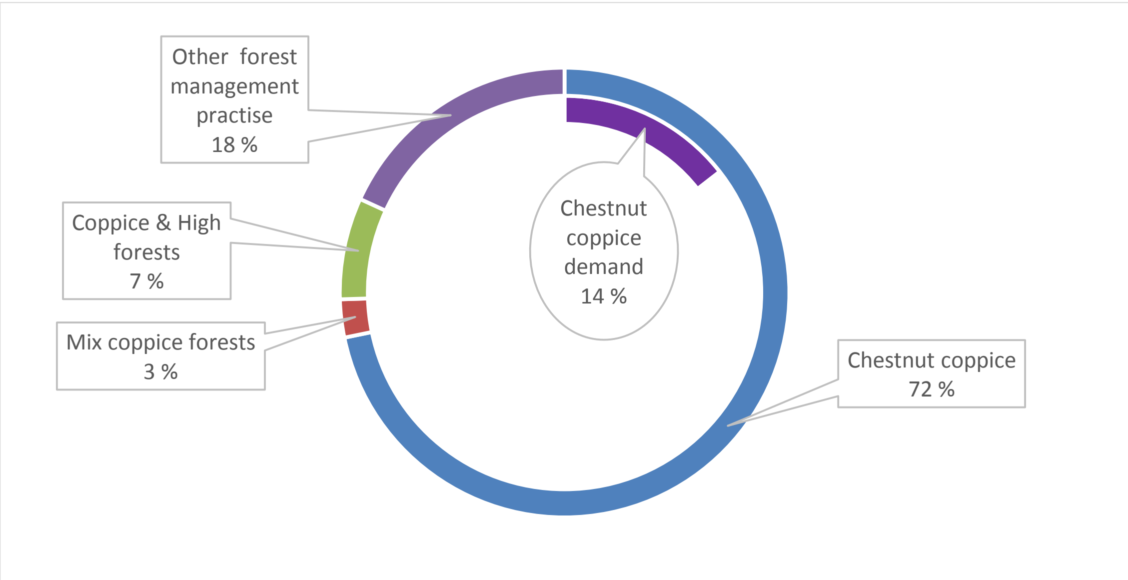
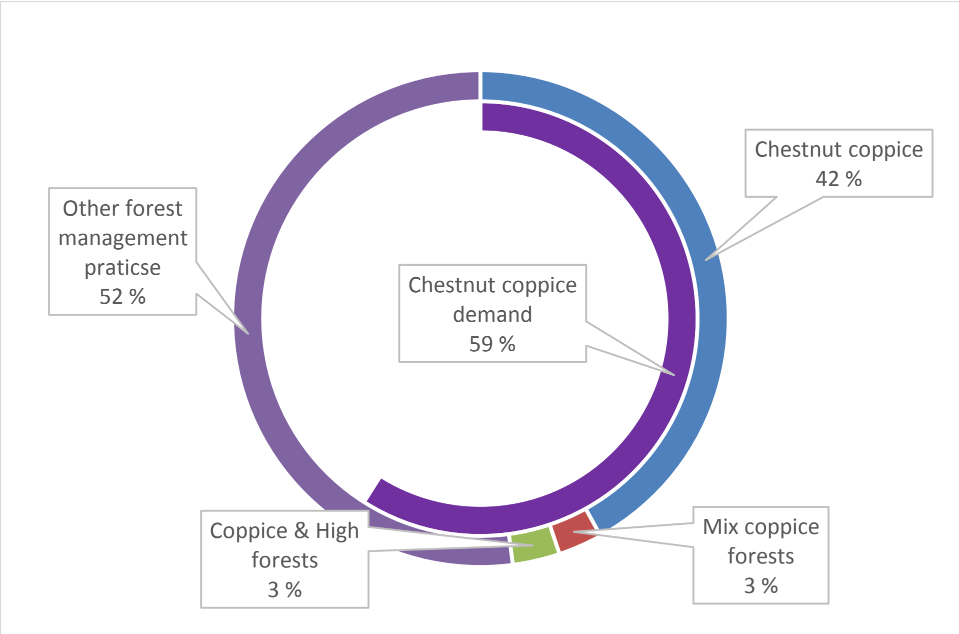
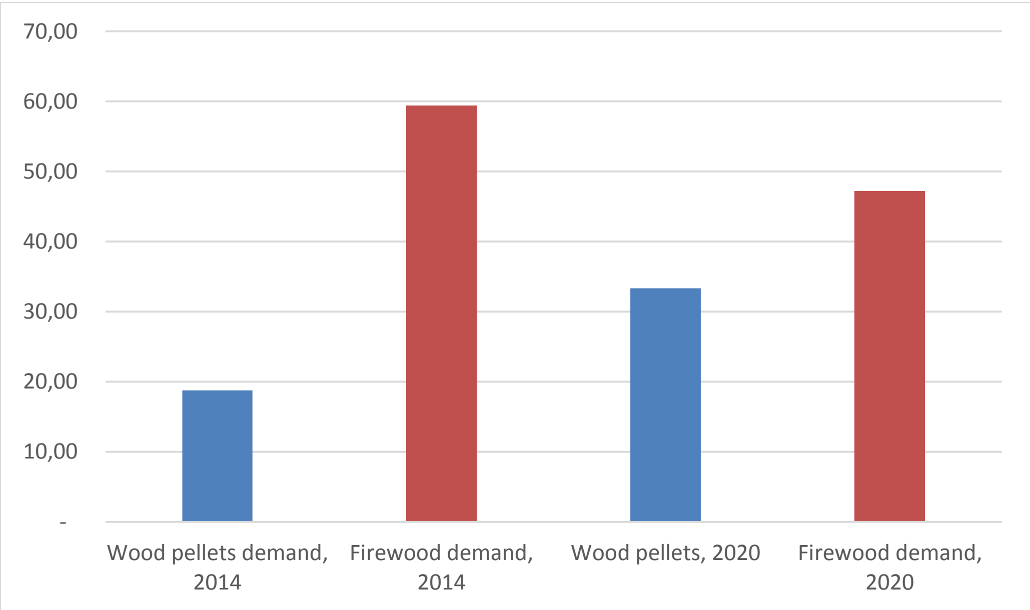


Figure 18 Balance between supply and demand observed on chestnut coppice forest priority list, La Foresta



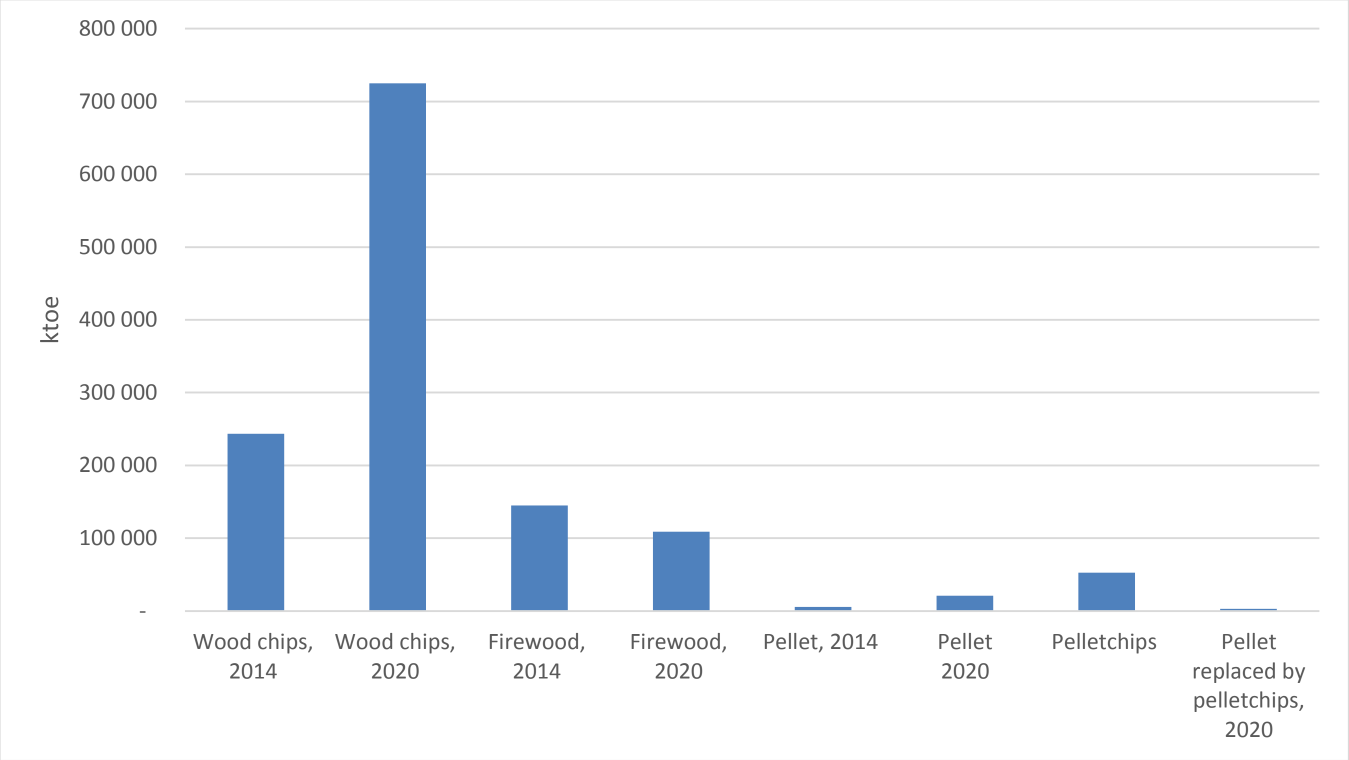
The results regarding the total wood fuels demand in the years 2014 (today scenario) and 2020 (future scenario) for pellets and firewood in the AiT Susa and Pinerolo (Figure 19) pointed out that the request for wood pellets will increase of 14.58 ktoe, while for firewood will decrease of 12.18 ktoe.

Figure 19 Demand of wood fuels in 2014 and 2020 in Susa and Pinerolo district (AiT)



A detailed analysis for the whole AiT Pinerolo, highlighted that the wood chips demand will extremely increase and the pelletchips will slightly replace wood pellets in heating appliances.

Figure 20 Wood fuels demand in the whole AiT Pinerolo, in the year 2014 and 2020



7 GIS results

Figure 21 and Figure 22 show the geographical boundary (blue line) of both supply and demand in a range of 30 km from the forestry companies Rossetto Legnami and La Foresta (see red circle).

Figure 21 Distance from Rossetto Legnami (red circle) to supply and demand

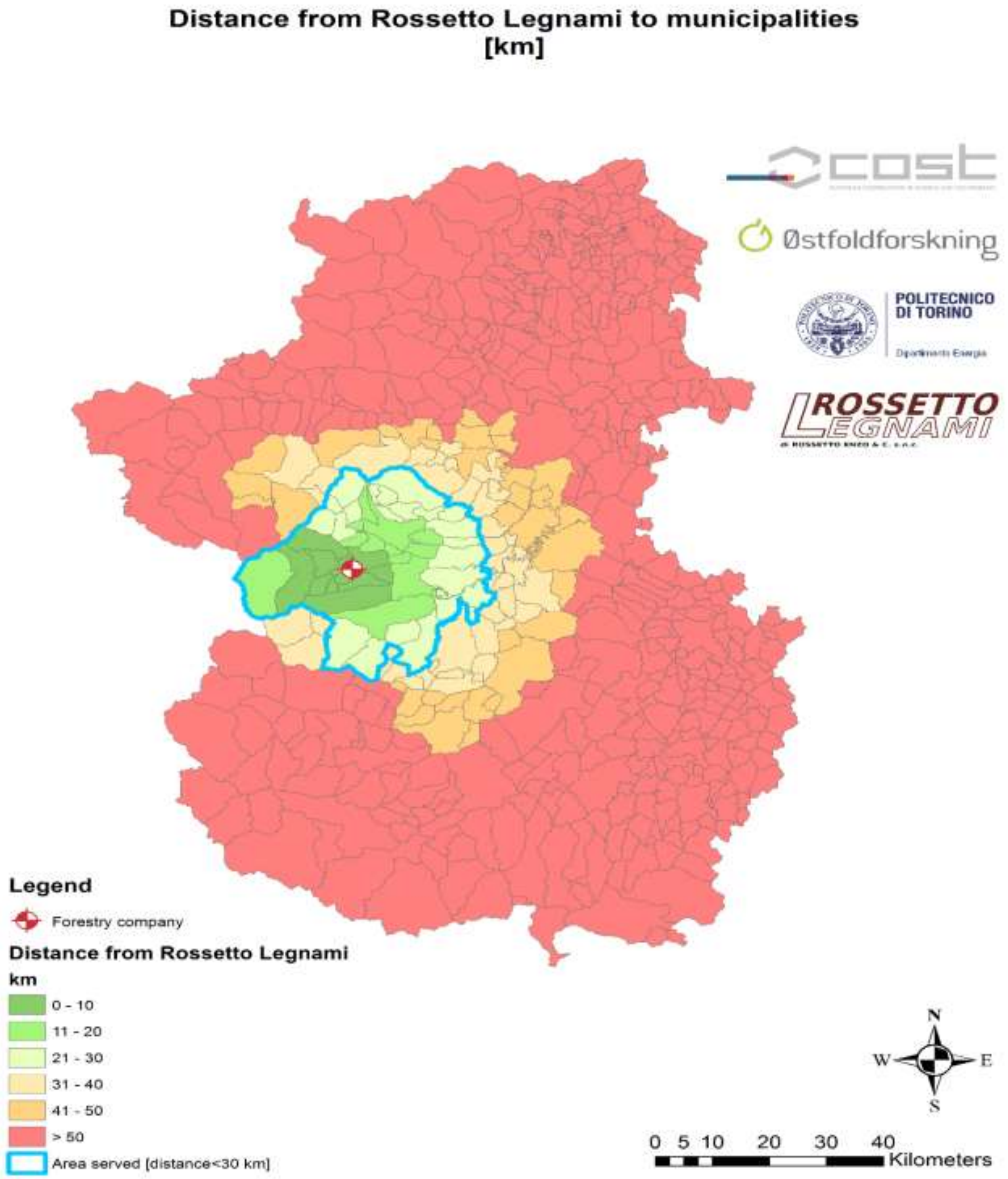


Figure 22 Distance from La Foresta (red circle) to supply and demand

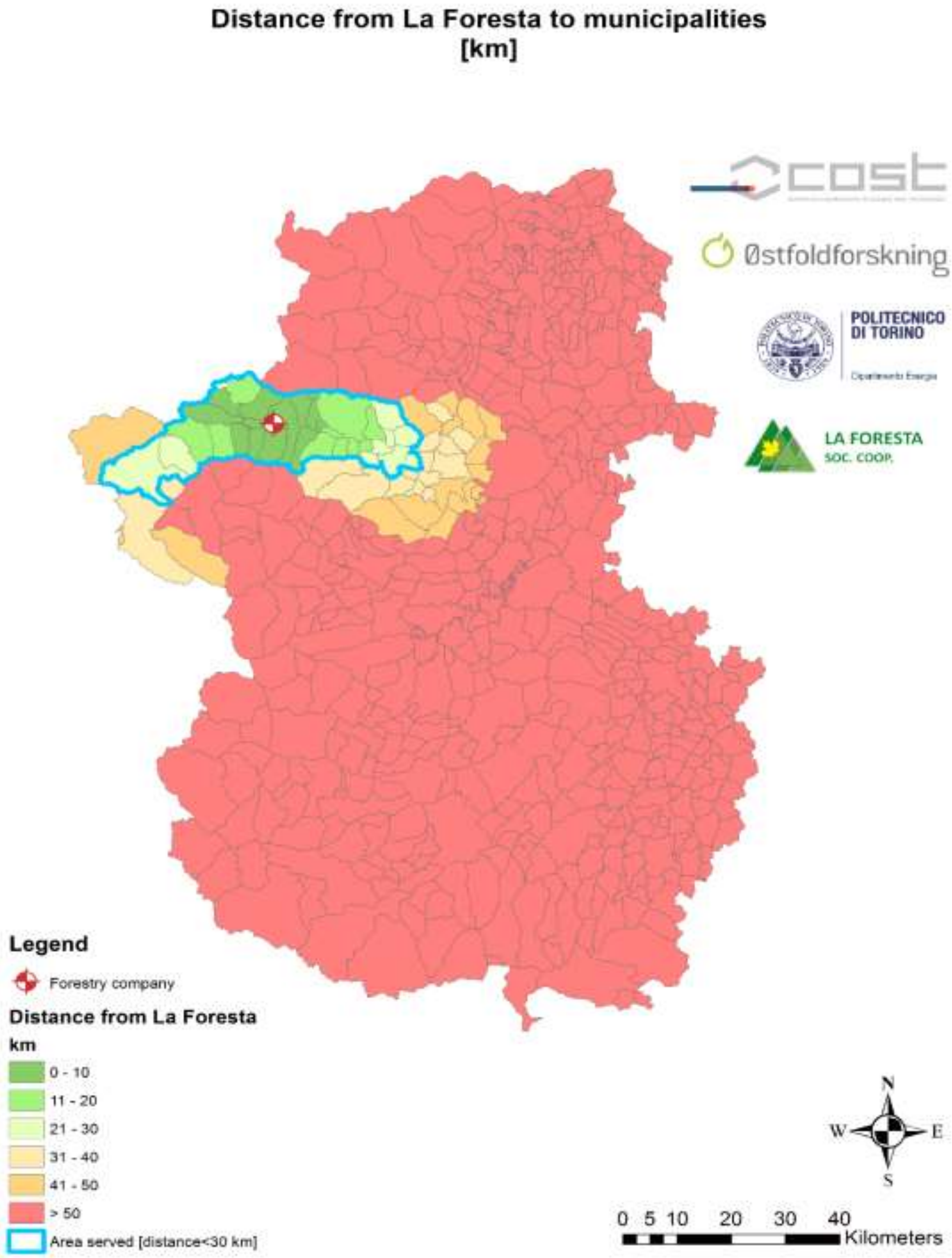


Figure 23 and

Figure 24 represent the supply and demand based on chestnut coppice aimed to pelletchips production respectively for Rossetto Legnami and La Foresta. Rossetto Legnami had a positive balance, the supply exceeded the demand of 16000 tons. Thus, the forest range around the forestry company highlighted its potential for wood fuels production specifically from coppicing. Instead, La Foresta had an opposite result. If all chestnut forest stands were harvested for achieving the required demand, the balance between total supply and demand would become negative (-180 tons) and so unsustainable.

Figure 23 Pelletchips from coppice chestnut forests: balance between supply versus demand, Rossetto Legnami

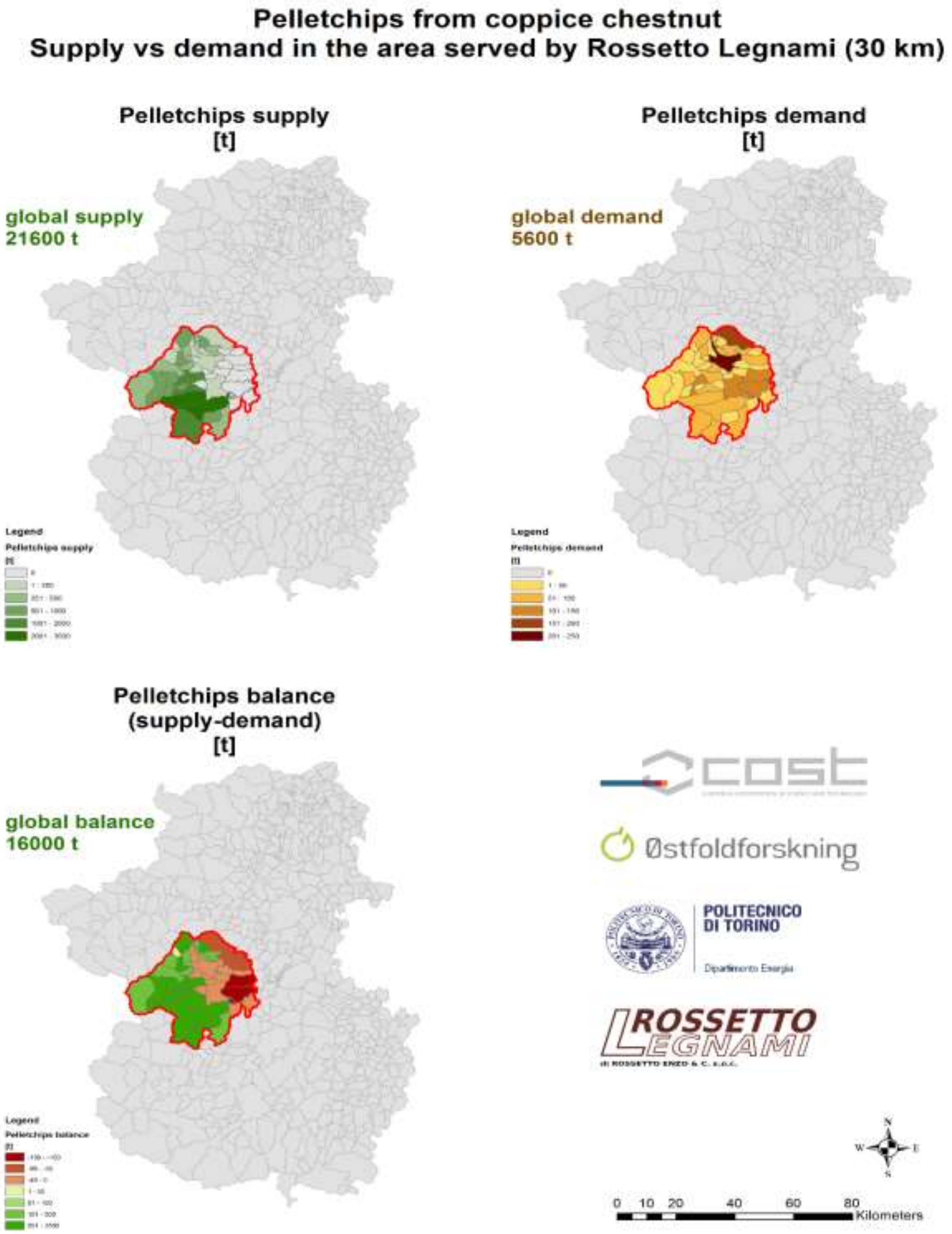
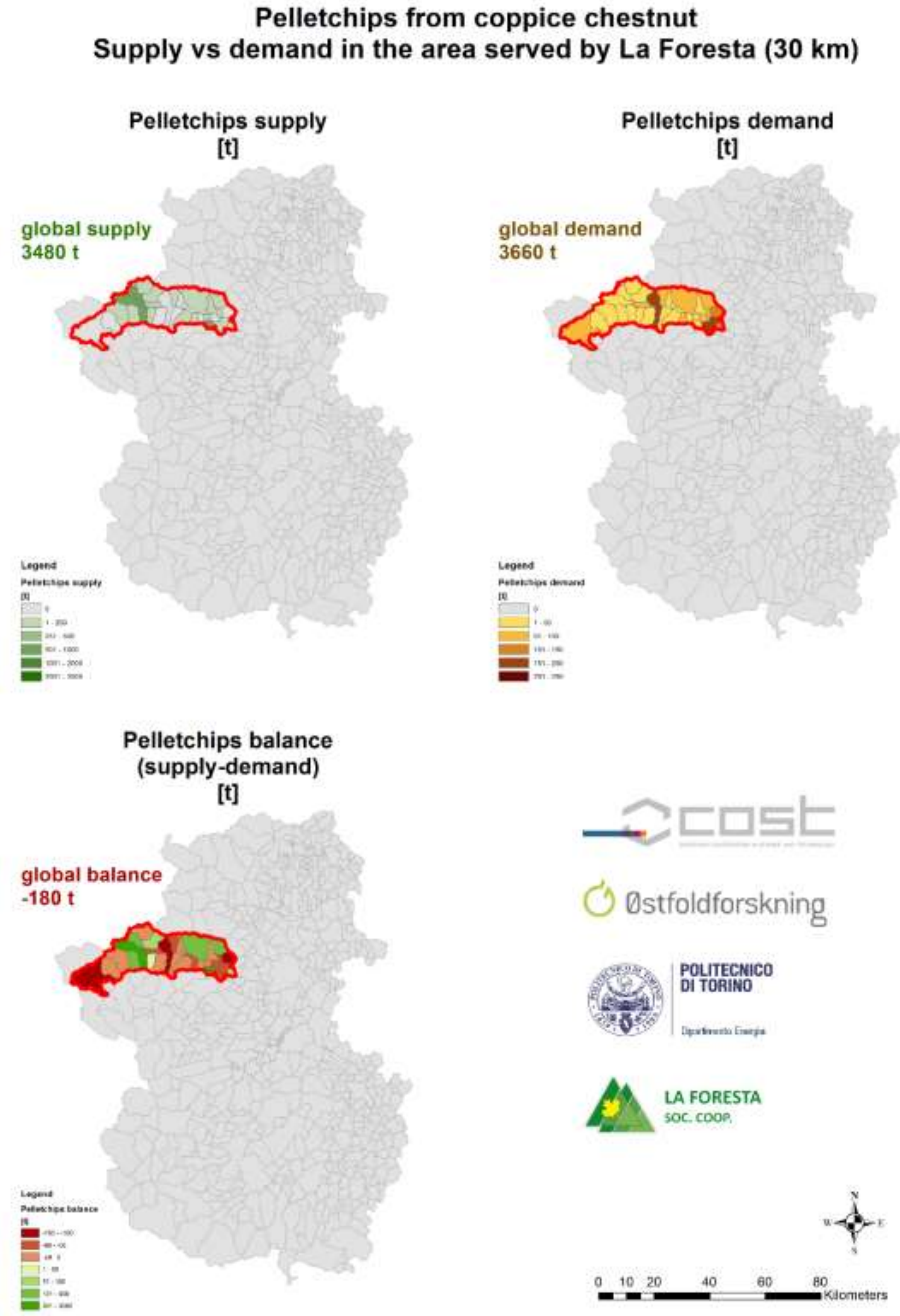


Figure 24 Pelletchips from coppice chestnut forests: balance between supply versus demand, La Foresta



8 Overall conclusions

The work presented in this report is performed thanks to the support of the COST action.

The results show the potentiality of traditional coppice forests to be managed for energy production. The outcomes from the Piedmont case study pointed out that local supply chain for wood fuels production had less emissions for the environmental category GWP, EP, AP and POCP that wood pellets imported from abroad (international supply chain).
In addition, the pelletchips supply chain had less emissions than the long transported wood pellets and it has similar hourly costs than wood chips supply chain.
Social LCA highlighted the very high risk of occupational injuries and fatal accidents in the Italian forestry sector. However, it is recommendable to develop adequate social indicators for assessing this risk.

The biomass and resource availability model together with the geographical information system were appropriate tools for discovering the location and the amount of biomass supply and the required demand specifically for coppice forest types (as chestnut).
The main outcome of the STSM was the application to real case study of the methodological framework developed for assessing the sustainability of wood fuels production from traditional forest coppice through the combination of three tools: LCSA, BRUSA and GIS. This framework can be applicable also in Scandinavia, after appropriate modifications.

The COST action was a successful experience for networking that could lead to future collaboration.

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